A Novel 2D Position Sensitive Silicon Detector with Micron Resolution for Heavy Ion Tracking

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Abstract

A new 2D position sensitive silicon detector for tracking of energetic heavy ions is under development in a program to study the radiation effect within a single cell. The detector is based on a concept of interleaved pixel electrodes arranged in a projective 2D strip readout (stripixel). A fine position resolution in the sub-micron range can be achieved by determining the centroid of the charge collected on pixel electrodes with a granularity in the range of 10µm. Preliminary test results with laser beam have shown that a position resolution better than 1 micron can be achieved at a charge level equivalent to 1GeV/n Fe ion with a 20µm pixel pitch. We will report test results of several stripixel designs from an up coming beam run with 1GeV/n Fe ions.

Introduction

The ability to place discrete numbers of particles in defined cellular and extracellular locations permits heavy-ion radiobiology to address specifically the impact of signal transduction between cellular compartments as well as issues related to intercellular communication at limiting low fluences where not all the cells in a population have been traversed by even a single particle. It will also address an important unanswered question: whether neurons that survive traversal by high atomic number-high energy (HZE) particles develop changes as a late consequence of the damage they incurred. Therefore, these low-fluence studies promise to aid in our understanding of the consequences of exposure to high-LET radiation such as encountered in the space radiation environment.

In the studies of single cell damage by energetic heavy ions, there arises the need for a detector with resolution in the range of 1-2 microns in both X and Y coordinates. The ion position uncertainty of traditional double-sided micro-strip and pixel Si detectors is greater than 10 µm rms. A novel detector [1] developed at BNL has the necessary properties to provide a position resolution better than 1 micron. Illustrated in Fig. 1, it is based on interleaved pixel electrodes arranged in a projective x-y readout, which makes possible position encoding with a moderate number of readout electronic channels. Taking advantage of the large energy deposited by the heavy ions in silicon and the diffusion of the charge carriers, a fine position resolution in the sub-micron range is achieved by determining the centroid of the charge collected on pixel electrodes with a granularity in the range of 10 microns. This concept is referred to as “stripixel” detector, as it combines the two-dimensional position resolution of a pixel electrode geometry with the simplicity of the projective readout of a double-sided strip detector.

Preliminary Results

The first batch of various detector designs has been fabricated. These designs covered pixel pitches ranging from 8.5µm to 85µm, with a thickness of 200µm and 16 readout channels in both X and Y axes. One set of digital centroid finding electronics has been adapted to be the readout system. This system was designed for multinode 2D position sensitive neutron imaging detectors with up to 16 and 17 channels in the X and Y axis respectively [2]

A pulsed 650nm red laser beam focused to about 7 µm in diameter was used to irradiate the detector from the back side. The total ionization from each laser pulse can be controlled by the pulse duration or the intensity. The centers of gravity of the signal charges from both axes were calculated for each laser pulse. The detectors position resolution was measured to be about 0.1µm rms at the 1.4pC charge expected from 1GeV/n Fe ions (Fig. 2).

One key finding in these bench tests is that the spread of charge carriers is much greater than that from original

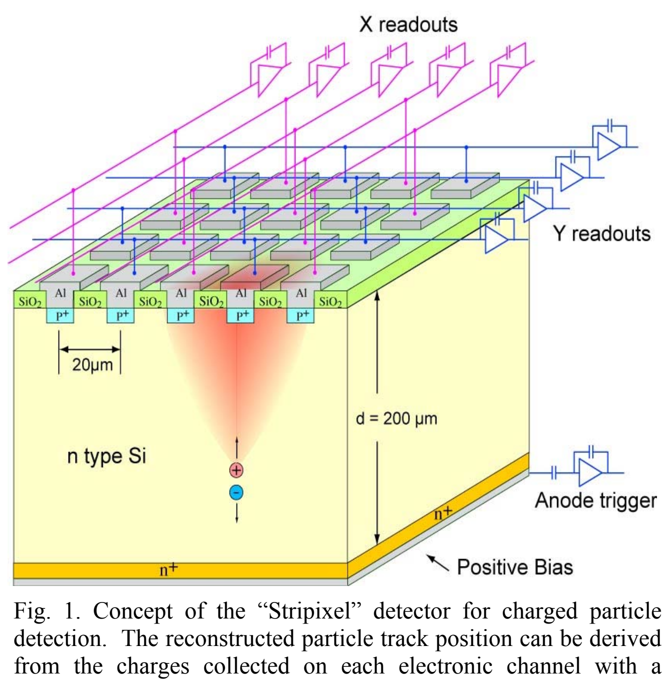

Fig. 1. Concept of the “Stripixel” detector for charged particle detection. The reconstructed particle track position can be derived from the charges collected on each electronic channel with a precision that is only a small fraction of the pitch of the pixels.

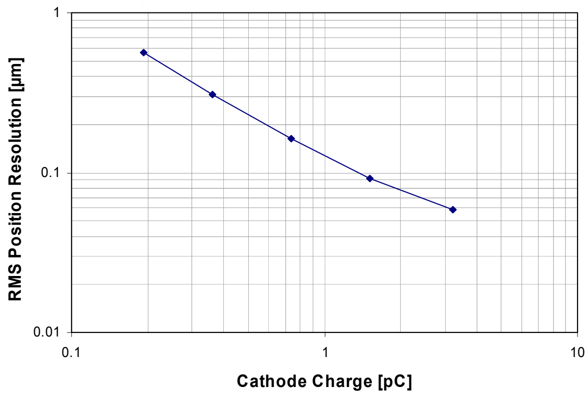

Fig. 2 Position resolution as a function of signal charge from a 20µm pitch, stripixel detector under a 650nm laser beam. The inverse linear relationship shows that the resolution is still noise limited.

calculations based on diffusion alone. Under a red laser, the measured charge spread profile is a strong function of the total injected charge as well as the bias voltage. Figure 3 shows the charge spread profile along one axis of a detector with a 20µm pitch under different laser intensities entering from the back side. Calculated rms spread from diffusion alone is only about 9µm. The additional spread is believed to result from two additional processes: 1) The charge density from the ionization is so high that the cloud of charge carriers in silicon rapidly expands under its own repulsive electric field; 2) The local electric field created by the charge cloud severely distorts the drift field, increasing the drift time and resulting in additional diffusion ("plasma effect").

The ionization tracks created by energetic heavy ions have very high charge density, but with a different carrier distribution compared with that from a laser. Preliminary beam test has shown that the charge spread is smaller than

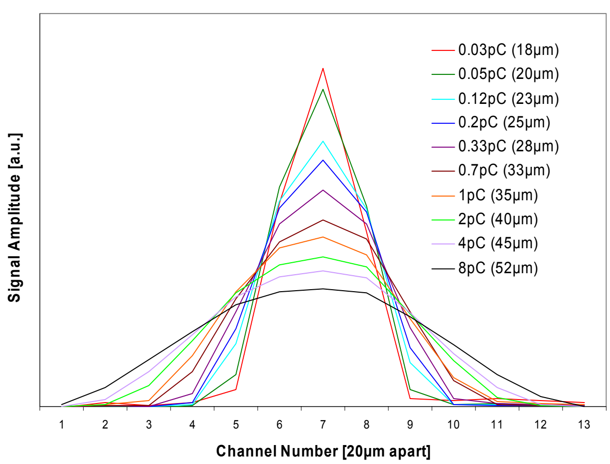

Fig.3 Spread of the charge carriers measured by the strips as a function of the total charge under a collimated 650nm laser beam. The numbers in parentheses are the sigma of Gaussian function fitted to the charge distributions.

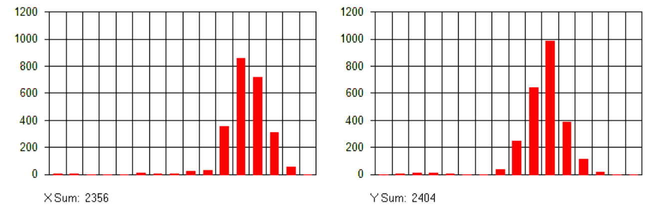

Fig. 4. Example of the signal charge collected from all channels on both axes of a stripixel detector with 20µm pitch. The incident particle is a 1GeV/n Fe ion. The total charge deposited on both axes is about 2.7pC.

that from a red laser at equivalent total charge level, and it is not sensitive to the bias voltage. Figure 4 shows the pulse heights recorded from all readout channels for a single 1GeV/n Fe ion.

The larger spread of the charge carriers in Si greatly benefits the detector design. To achieve a good position response through charge interpolation, the maximum feature size of the pixel needs to be smaller than the spread of the charge. A larger charge spread enables us to increase the pixel size and therefore the active area of the detector without degrading the linearity of the detector. In addition, we are investigating using resistive charge division [3] on these detectors to further increase the detector's active area.

Linearity in position response has been evaluated on these designs under uniform irradiation of alpha particles. Based on these studies, a second batch of detectors with improved designs is being fabricated. We are planning to test a few selected designs from this new batch at the NASA Space Radiation Laboratory (NSRL) at BNL this summer to determine the position resolution and linearity in position response under 1GeV/n Fe ions. One of these tests will be a position resolution measurement with two detectors closely stacked to minimize errors caused by multiple scattering in the beam. The results will be presented at the conference.

References

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[2] J. A. Mead, J. A. Harder, N. A. Schaknowski, G. C. Smith and B. Yu, "Digital Centroid Finding Electronics for Multi-node 2D Detectors," pres. at 2003 Nuclear Science Symposium, October 19-25, 2003, Portland, Oregon, to be published in IEEE Trans. Nucl. Sci.

[3] V. Radeka and R.A. Boie, "Centroid Finding method for position-sensitive detectors," Nucl. Instr. and Meth. 178 (1980), p543.